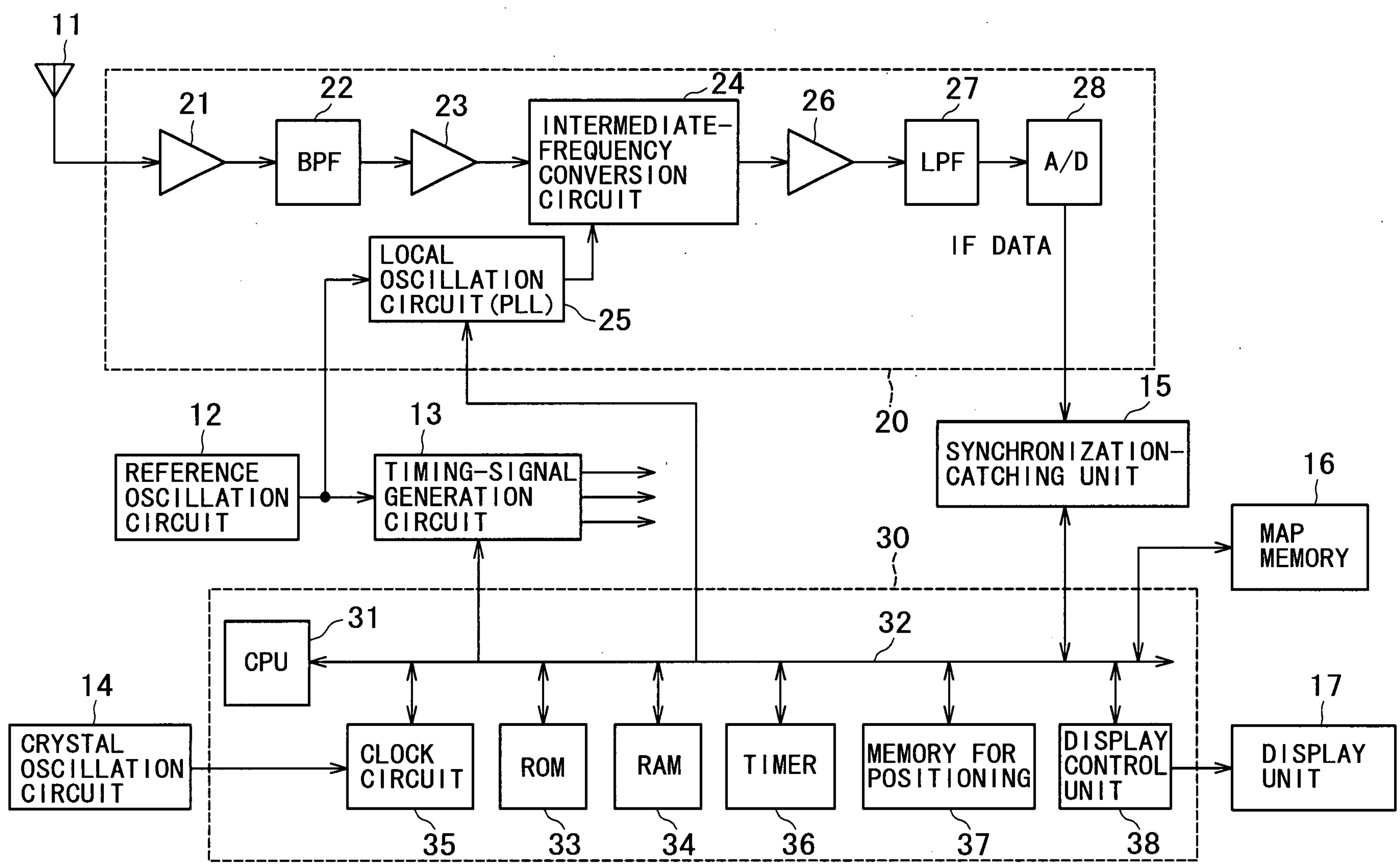
F I G. 1


11
21
22
BPF
23
24
INTERMEDIATE-FREQUENCY CONVERSION CIRCUIT
26
27
LPF
28
A/D
IF DATA
LOCAL OSCILLATION CIRCUIT (PLL)
25
20
12
REFERENCE OSCILLATION CIRCUIT
13
TIMING-SIGNAL GENERATION CIRCUIT
15
SYNCHRONIZATION-CATCHING UNIT
16
MAP MEMORY
30
31
CPU
32
14
CRYSTAL OSCILLATION CIRCUIT
CLOCK CIRCUIT
35
ROM
33
RAM
34
TIMER
36
MEMORY FOR POSITIONING
37
DISPLAY CONTROL UNIT
38
17
DISPLAY UNIT

F I G. 2

$$ti = Tci + Tmi \qquad \cdots\cdots (1a)$$

ti:DIFFUSION-CODE TRANSMISSION TIME
Tci:VALUE OF DIGITS EXPRESSING A NUMBER SMALLER THAN 1 msec
(PHASE OF DIFFUSION CODE)
Tmi:VALUE OF DIGITS EXPRESSING A NUMBER EQUAL TO OR GREATER THAN 1 msec

$$ti = Tci + Ti + to \qquad \cdots\cdots (1b)$$

ti:DIFFUSION-CODE TRANSMISSION TIME
Tci:VALUE OF DIGITS EXPRESSING A NUMBER SMALLER THAN 1 msec(PHASE OF DIFFUSION CODE)
(Ti+to):VALUE OF DIGITS EXPRESSING A NUMBER EQUAL TO OR GREATER THAN 1 msec
to:REFERENCE TIME(COMMON TO SATELLITES)
Ti:DIFFERENTIAL TIME

FIG. 3

$$fi(Xo,\ \tau,\ to) = |Xi(ti) - Xo| - c\ \{(tr - ti) + \tau\}$$
$$= |Xi(Tci + Ti + to) - Xo|$$
$$- c\ \{tr - (Tci + Ti + to) + \tau\} = 0 \qquad \cdots\cdots (2)$$

$$Xi(ti) = (xi(ti)\ yi(ti)\ zi(ti))^T \qquad \cdots\cdots (3)$$

$$Xo = (xo\ \ yo\ \ zo)^T \qquad \cdots\cdots (4)$$

$$f1(Xo,\ \tau,\ to) = |X1(Tc1 + T1 + to) - Xo|$$
$$- c\ \{tr - (Tc1 + T1 + to) + \tau\} = 0 \qquad \cdots\cdots (2a)$$

$$f2(Xo,\ \tau,\ to) = |X2(Tc2 + T2 + to) - Xo|$$
$$- c\ \{tr - (Tc2 + T2 + to) + \tau\} = 0 \qquad \cdots\cdots (2b)$$

$$f3(Xo,\ \tau,\ to) = |X3(Tc3 + T3 + to) - Xo|$$
$$- c\ \{tr - (Tc3 + T3 + to) + \tau\} = 0 \qquad \cdots\cdots (2c)$$

$$f4(Xo,\ \tau,\ to) = |X4(Tc4 + T4 + to) - Xo|$$
$$- c\ \{tr - (Tc4 + T4 + to) + \tau\} = 0 \qquad \cdots\cdots (2d)$$

$$f5(Xo,\ \tau,\ to) = |X5(Tc5 + T5 + to) - Xo|$$
$$- c\ \{tr - (Tc5 + T5 + to) + \tau\} = 0 \qquad \cdots\cdots (2e)$$

FIG. 4

POINT OF INTEREST

$$(Xo(n),\ \tau(n),\ to(n)) \quad \cdots\cdots (11)$$

$$\Delta fi=\frac{\partial fi}{\partial xo(n)}\Delta xo+\frac{\partial fi}{\partial yo(n)}\Delta yo+\frac{\partial fi}{\partial zo(n)}\Delta zo +\frac{\partial fi}{\partial \tau(n)}\Delta \tau+\frac{\partial fi}{\partial to(n)}\Delta to \quad \cdots\cdots (12)$$

$$fi(Xo(n),\ \tau(n),\ to(n))+\Delta fi=0 \quad \cdots\cdots (13)$$

$$(\Delta Xo,\ \Delta\tau,\ \Delta to) \quad \cdots\cdots (14)$$

$$\Delta Xo=(\Delta xo\ \ \Delta yo\ \ \Delta zo)^T \quad \cdots\cdots (15)$$

$$\frac{\partial fi}{\partial xo(n)}=\left.\frac{\partial fi}{\partial xo}\right|_{xo=xo(n)} \quad \cdots\cdots (16)$$

$$\begin{aligned} &F(Xo(n),\ \tau(n),\ to(n))+\Delta F \\ &=F(Xo(n),\ \tau(n),\ to(n))+J(Xo(n),\ \tau(n),\ to(n))\ \Delta P \\ &=0 \end{aligned} \quad \cdots\cdots (17)$$

$$F=(f1\ \ f2\ \ f3\ \ f4\ \ f5)^T \quad \cdots\cdots (18)$$

$$\Delta P=(\Delta xo\ \ \Delta yo\ \ \Delta\tau\ \ \Delta to)^T \quad \cdots\cdots (19)$$

FIG. 5

$$J(Xo(n),\ \tau(n),\ to(n)) = \begin{bmatrix} \frac{\partial f1}{\partial xo(n)} & \frac{\partial f1}{\partial yo(n)} & \frac{\partial f1}{\partial zo(n)} & \frac{\partial f1}{\partial \tau(n)} & \frac{\partial f1}{\partial to(n)} \\ \frac{\partial f2}{\partial xo(n)} & \frac{\partial f2}{\partial yo(n)} & \frac{\partial f2}{\partial zo(n)} & \frac{\partial f2}{\partial \tau(n)} & \frac{\partial f2}{\partial to(n)} \\ \frac{\partial f3}{\partial xo(n)} & \frac{\partial f3}{\partial yo(n)} & \frac{\partial f3}{\partial zo(n)} & \frac{\partial f3}{\partial \tau(n)} & \frac{\partial f3}{\partial to(n)} \\ \frac{\partial f4}{\partial xo(n)} & \frac{\partial f4}{\partial yo(n)} & \frac{\partial f4}{\partial zo(n)} & \frac{\partial f4}{\partial \tau(n)} & \frac{\partial f4}{\partial to(n)} \\ \frac{\partial f5}{\partial xo(n)} & \frac{\partial f5}{\partial yo(n)} & \frac{\partial f5}{\partial zo(n)} & \frac{\partial f5}{\partial \tau(n)} & \frac{\partial f5}{\partial to(n)} \end{bmatrix} \quad \cdots\cdots (21)$$

$$\frac{\partial fi}{\partial xo(n)} = -\frac{xi(Tci+Ti+to(n)) - xo(n)}{|Xi(Tci+Ti+to(n)) - Xo(n)|} \quad \cdots\cdots (22)$$

$$\frac{\partial fi}{\partial yo(n)} = -\frac{yi(Tci+Ti+to(n)) - yo(n)}{|Xi(Tci+Ti+to(n)) - Xo(n)|} \quad \cdots\cdots (23)$$

$$\frac{\partial fi}{\partial zo(n)} = -\frac{zi(Tci+Ti+to(n)) - zo(n)}{|Xi(Tci+Ti+to(n)) - Xo(n)|} \quad \cdots\cdots (24)$$

$$\frac{\partial fi}{\partial \tau o(n)} = -c \quad \cdots\cdots (25)$$

$$\frac{\partial fi}{\partial To(n)} = -\frac{(Xi(Tci+Ti+to(n)) - Xo(n)) \cdot Vi(Tci+Ti+to(n))}{|Xi(Tci+Ti+to(n)) - Xo(n)|} + C \quad \cdots\cdots (26)$$

$$A \cdot B = (Xi(Tci+Ti+to(n)) - Xo(n)) \cdot Vi(Tci+Ti+to(n)) \quad \cdots\cdots (27)$$

FIG. 6

INITIAL VALUES

$$(Xo(0),\ \tau(0),\ to(0)) = (Xoa,\ 0,\ toa) \quad \cdots\cdots (31)$$

$Xo(0)=Xoa$: APPROXIMATE POSITION OF RECEIVER
$\tau(0)$: INITIAL VALUE OF ERROR τ OF RECEIVER INTERNAL CLOCK
$to(0)=toa$: INITIAL VALUE OF REFERENCE TIME to
(TIME INDICATED BY INTERNAL CLOCK OF RECEIVER AT ITERATION COMPUTATION START TIME)

FIG. 7

NEXT POINT OF INTEREST

$$(Xo(n+1),\ \tau(n+1),\ to(n+1)) = (Xo(n)+\Delta Xo,\ \tau(n)+\Delta\tau,\ to(n)+\Delta to) \quad \cdots\cdots (33)$$

CONVERGENCE CRITERIA (ε : CONSTANT)

$$|\Delta Xo| < \varepsilon \quad \cdots\cdots (35)$$

$$|\Delta P| < \varepsilon \quad \cdots\cdots (36)$$

$$|F\ (Xo(n),\ \tau(n),\ to(n)\ | < \varepsilon \quad \cdots\cdots (37)$$

FIG. 8

CALCULATION OF DIFFERENTIAL TIME Ti

$$t1=Tc1+to \quad \cdots\cdots (1c)$$

$$ti=Tci+Ti+to \quad (i \geqq 2) \quad \cdots\cdots (1d)$$

$$Ti=(Ti+to)-to=(ti-Tci)-(t1-Tc1) \quad \cdots\cdots (41)$$

$$c(tr-ti)=|Xi(ti)-Xo| \quad \cdots\cdots (42)$$

$$ti=tr-\frac{|Xi(ti)-Xo|}{c} \quad \cdots\cdots (43)$$

$$t1=tr-\frac{|X1(t1)-Xo|}{c} \quad \cdots\cdots (44)$$

$$Ti=\left(\frac{|X1(t1)-Xo|}{c}+Tc1\right)-\left(\frac{|Xi(ti)-Xo|}{c}+Tci\right) \quad \cdots\cdots (45)$$

$$c\times 1.0\times 10^{-3}\ [m]\simeq 3.0\times 10^{5}\ [m] \quad \cdots\cdots (46)$$

$$ti=t1-2.0\times 10^{-2}\ [SECONDS] \quad \cdots\cdots (47)$$

FIG. 9

TOLERANCE OF APPROXIMATE POSITION OF RECEIVER

$$cTi=(|X1(t1)-Xo|+cTc1)-(|Xi(ti)-Xo|+cTci) \quad \cdots\cdots(51)$$

$$\begin{aligned}&(|X1(t1)-(Xo+\Delta X)|+cTc1)\\&\quad-(|Xi(ti)-(Xo+\Delta X)|+cTci)\\&=(|X1(t1)-Xo|+|\Delta X|+cTc1)\\&\quad-(|Xi(ti)-Xo|-|\Delta X|+cTci)\\&=(|X1(t1)-Xo|+cTc1)\\&\quad-(|Xi(ti)-Xo|+cTci)+2|\Delta X|\\&=cTi+2|\Delta X|\end{aligned} \quad \cdots\cdots(52)$$

$|\Delta X|$: DISTANCE BETWEEN COORDINATES REPRESENTING APPROXIMATE POSITION OF RECEIVER AND ACTUAL POSITION OF RECEIVER

$$|A|>|B| \quad \cdots\cdots(63)$$

$$|A|-|B|\leqq|A-B|\leqq|A|+|B| \quad \cdots\cdots(64)$$

$$\begin{aligned}&|Xi(ti)-(Xo+\Delta X)|\\&\quad=|(Xi(ti)-Xo)-\Delta X|\end{aligned} \quad \cdots\cdots(65)$$

$$A=Xi(ti)-Xo \quad \cdots\cdots(66)$$

$$B=\Delta X \quad \cdots\cdots(67)$$

$$\begin{aligned}&|Xi(ti)-Xo|-|\Delta X|\\&\quad\leqq|(Xi(ti)-Xo)-\Delta X|\\&\quad\leqq|Xi(ti)-Xo|+|\Delta X|\end{aligned} \quad \cdots\cdots(68)$$

FIG. 10

TOLERANCE OF ERROR OF RECEIVER INTERNAL TIME

$$t1+\Delta t=ti+\Delta t+2.0\times10^{-2}\ [\text{SECONDS}] \quad \cdots\cdots(53)$$

$$\begin{aligned}
&(|X1(t1+\Delta t)-Xo|+cTc1)\\
&\quad-(|Xi(t1+\Delta t)-Xo|+cTci)\\
&=(|X1(t1+\Delta t)-Xo|+cTc1)\\
&\quad-(|Xi(ti+\Delta t+2.0\times10^{-2})-Xo|+cTci)\\
&=(|X1(t1)-Xo|+\Delta t\times1.0\times10^{3}+cTc1)\\
&\quad-(|Xi(ti)-Xo|-\Delta t+2.0\times10^{-2})\times1.0\times10^{3}+cTci)\\
&=(|X1(t1)-Xo|+cTc1)-(|Xi(ti)-Xo|+cTci)\\
&\quad+(2\Delta t+2.0\times10^{-2})\times1.0\times10^{3}\\
&=cTi+(2\Delta t+2.0\times10^{-2})\times1.0\times10^{3} \quad \cdots\cdots(54)
\end{aligned}$$

$$\begin{aligned}
\Delta d&=(2\Delta t+2.0\times10^{-2})\times1.0\times10^{3}\ [\text{m}]\\
&\simeq2\Delta t\times1.0\times10^{3}\ [\text{m}] \quad \cdots\cdots(55)
\end{aligned}$$

FIG. 11

$$2|\Delta X|+2|\Delta t|\times 1.0\times 10^{3}<1.5\times 10^{5} \quad \cdots\cdots (56)$$

$$|\Delta X|+1.0\times 10^{3}\times|\Delta t|<7.5\times 10^{4} \quad \cdots\cdots (57)$$

FIG. 12

SECOND METHOD

$$f1(Xo, \tau, to) = |X1(Tc1+T1+to)-Xo| - c\{tr-(Tc1+T1+to)+\tau\} = 0 \quad \cdots\cdots (2a)$$

$$f2(Xo, \tau, to) = |X2(Tc2+T2+to)-Xo| - c\{tr-(Tc2+T2+to)+\tau\} = 0 \quad \cdots\cdots (2b)$$

$$f3(Xo, \tau, to) = |X3(Tc3+T3+to)-Xo| - c\{tr-(Tc3+T3+to)+\tau\} = 0 \quad \cdots\cdots (2c)$$

$$f4(Xo, \tau, to) = |X4(Tc4+T4+to)-Xo| - c\{tr-(Tc4+T4+to)+\tau\} = 0 \quad \cdots\cdots (2d)$$

$$f5(Xo, \tau, to) = |X5(Tc5+T5+to)-Xo| - c\{tr-(Tc5+T5+to)+\tau\} = 0 \quad \cdots\cdots (2e)$$

$$f6(Xo, \tau, to) = |X6(Tc6+T6+to)-Xo| - c\{tr-(Tc6+T6+to)+\tau\} = 0 \quad \cdots\cdots (2f)$$

$$\Delta P = (J^T J)^{-1} J^T (-F) \quad \cdots\cdots (61)$$

FIG. 13

THIRD METHOD

$$f5(Xo) = |Xo| - |Xoa| = 0 \quad \cdots\cdots (71)$$

Xoa: APPROXIMATE POSITION OF RECEIVER

$$\frac{\partial f5}{\partial xo(n)} = \frac{xo(n)}{|Xo(n)|} \quad \cdots\cdots (72)$$

$$\frac{\partial f5}{\partial yo(n)} = \frac{yo(n)}{|Xo(n)|} \quad \cdots\cdots (73)$$

$$\frac{\partial f5}{\partial zo(n)} = \frac{zo(n)}{|Xo(n)|} \quad \cdots\cdots (74)$$

$$\frac{\partial f5}{\partial \tau(n)} = 0 \quad \cdots\cdots (75)$$

$$\frac{\partial f5}{\partial to(n)} = 0 \quad \cdots\cdots (76)$$

F I G. 1 4

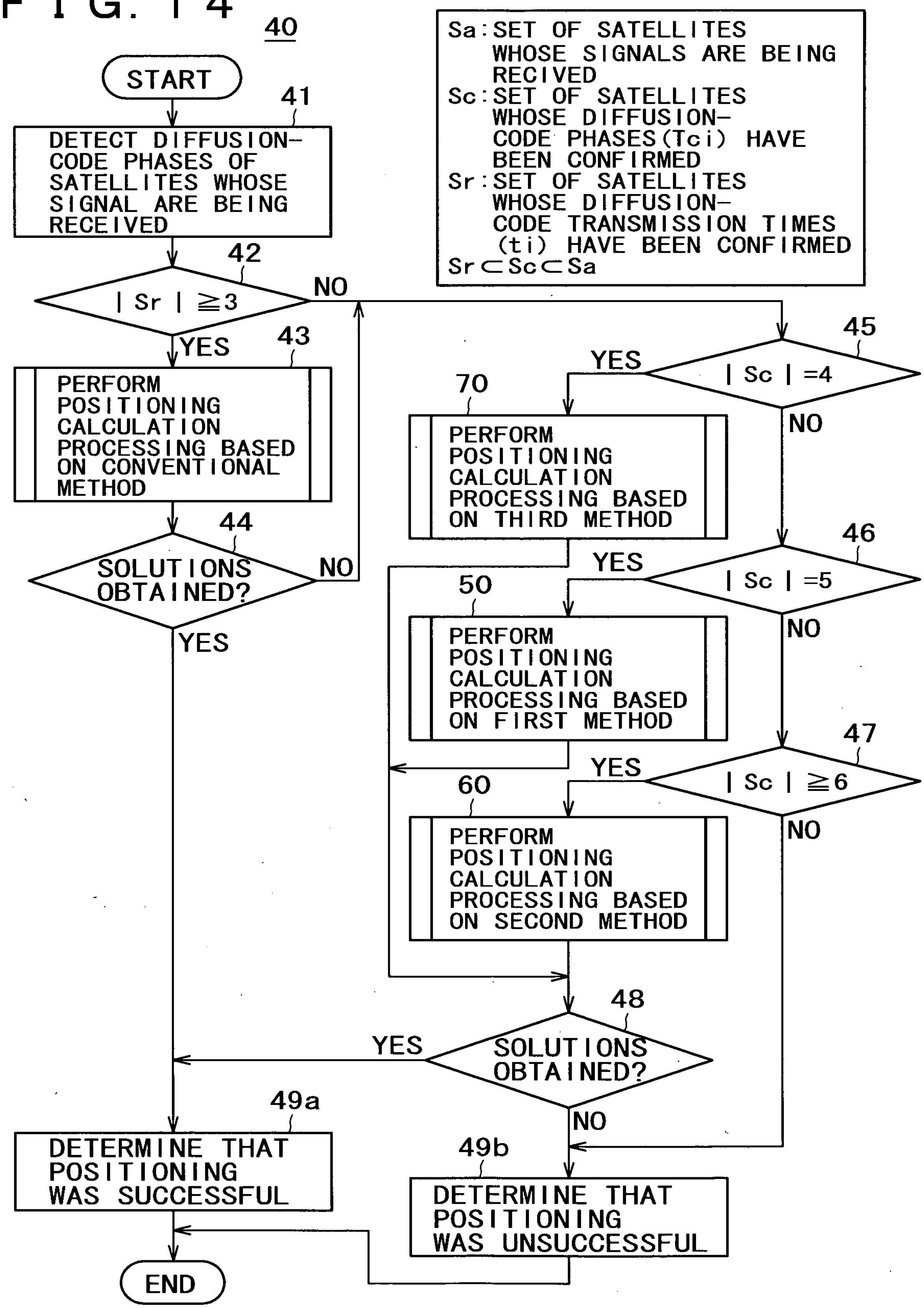

40
Sa: SET OF SATELLITES WHOSE SIGNALS ARE BEING RECIVED
Sc: SET OF SATELLITES WHOSE DIFFUSION-CODE PHASES (Tci) HAVE BEEN CONFIRMED
Sr: SET OF SATELLITES WHOSE DIFFUSION-CODE TRANSMISSION TIMES (ti) HAVE BEEN CONFIRMED
Sr⊂Sc⊂Sa
START
41
DETECT DIFFUSION-CODE PHASES OF SATELLITES WHOSE SIGNAL ARE BEING RECEIVED
42
| Sr | ≧3
NO
YES
43
PERFORM POSITIONING CALCULATION PROCESSING BASED ON CONVENTIONAL METHOD
44
SOLUTIONS OBTAINED?
NO
YES
45
| Sc | =4
YES
NO
70
PERFORM POSITIONING CALCULATION PROCESSING BASED ON THIRD METHOD
46
| Sc | =5
YES
NO
50
PERFORM POSITIONING CALCULATION PROCESSING BASED ON FIRST METHOD
47
| Sc | ≧6
YES
NO
60
PERFORM POSITIONING CALCULATION PROCESSING BASED ON SECOND METHOD
48
SOLUTIONS OBTAINED?
YES
NO
49a
DETERMINE THAT POSITIONING WAS SUCCESSFUL
49b
DETERMINE THAT POSITIONING WAS UNSUCCESSFUL
END

FIG. 15

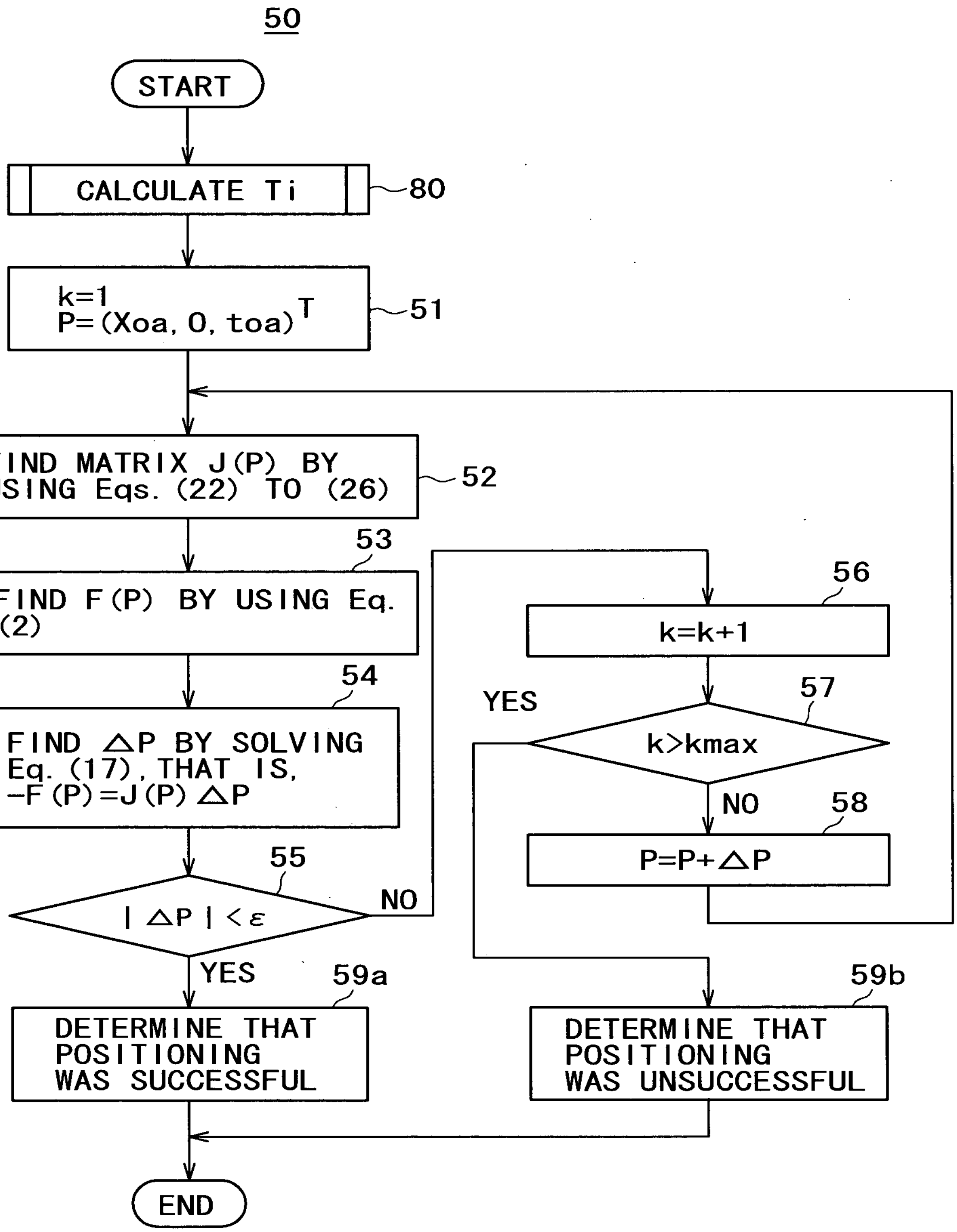
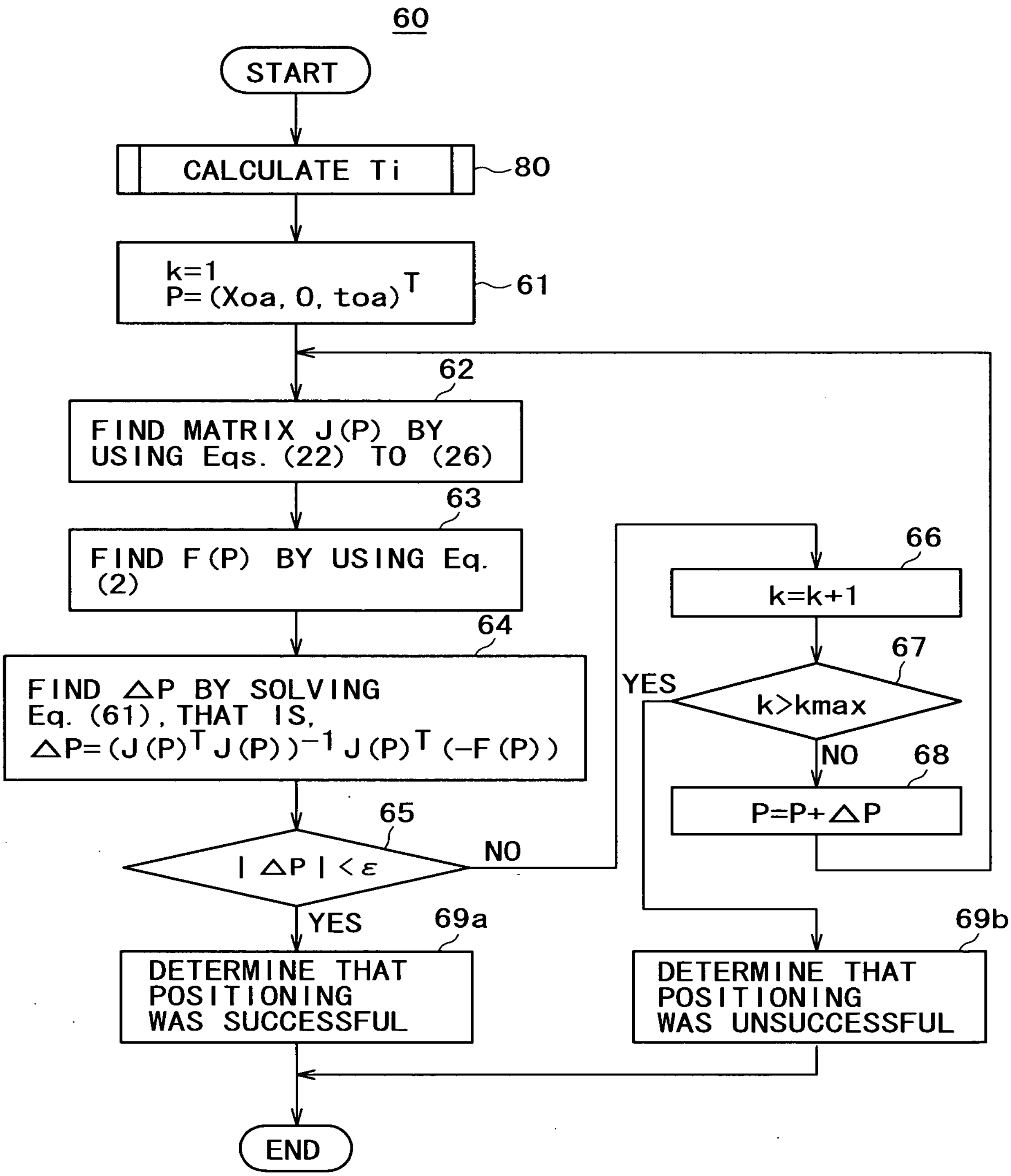

50
START
CALCULATE Ti
80
k=1
P=(Xoa, 0, toa)T
51
FIND MATRIX J(P) BY USING Eqs. (22) TO (26)
52
53
FIND F(P) BY USING Eq. (2)
54
FIND △P BY SOLVING Eq. (17), THAT IS, −F(P)=J(P)△P
55
|△P|<ε
NO
YES
56
k=k+1
57
k>kmax
YES
NO
58
P=P+△P
59a
DETERMINE THAT POSITIONING WAS SUCCESSFUL
59b
DETERMINE THAT POSITIONING WAS UNSUCCESSFUL
END

FIG. 16



60
START
CALCULATE Ti
80
k=1
P=(Xoa, 0, toa)T
61
62
FIND MATRIX J(P) BY USING Eqs. (22) TO (26)
63
FIND F(P) BY USING Eq. (2)
64
FIND △P BY SOLVING Eq. (61), THAT IS, △P=(J(P)T J(P))−1 J(P)T (−F(P))
65
|△P|<ε
NO
YES
66
k=k+1
67
k>kmax
YES
NO
68
P=P+△P
69a
DETERMINE THAT POSITIONING WAS SUCCESSFUL
69b
DETERMINE THAT POSITIONING WAS UNSUCCESSFUL
END

FIG. 17

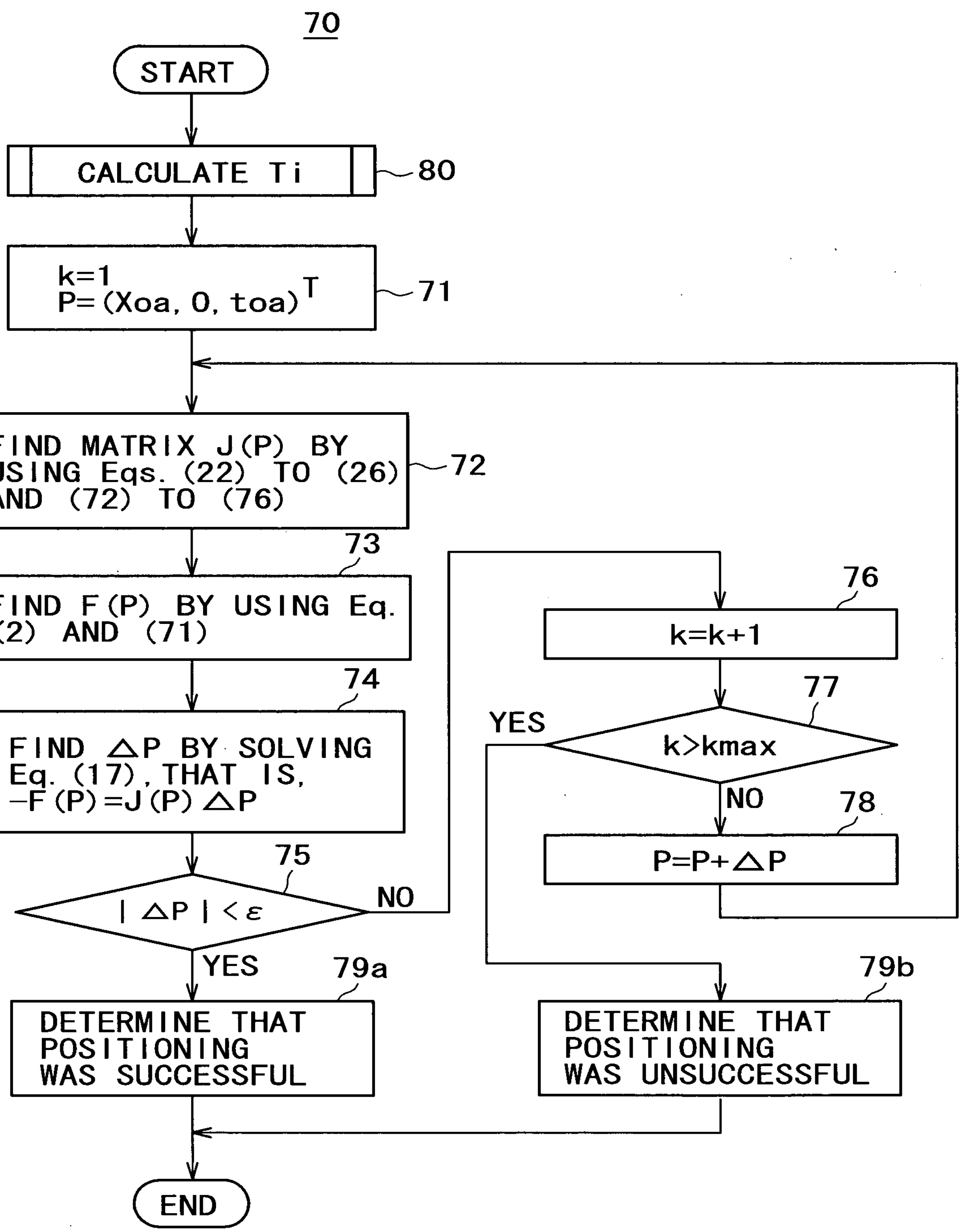

70
START
CALCULATE Ti
80
k=1
P=(Xoa, 0, toa)^T
71
FIND MATRIX J(P) BY USING Eqs. (22) TO (26) AND (72) TO (76)
72
73
FIND F(P) BY USING Eq. (2) AND (71)
74
FIND △P BY SOLVING Eq. (17), THAT IS, −F(P)=J(P)△P
75
\|△P\|<ε
NO
YES
76
k=k+1
77
k>kmax
YES
NO
78
P=P+△P
79a
DETERMINE THAT POSITIONING WAS SUCCESSFUL
79b
DETERMINE THAT POSITIONING WAS UNSUCCESSFUL
END

FIG. 18

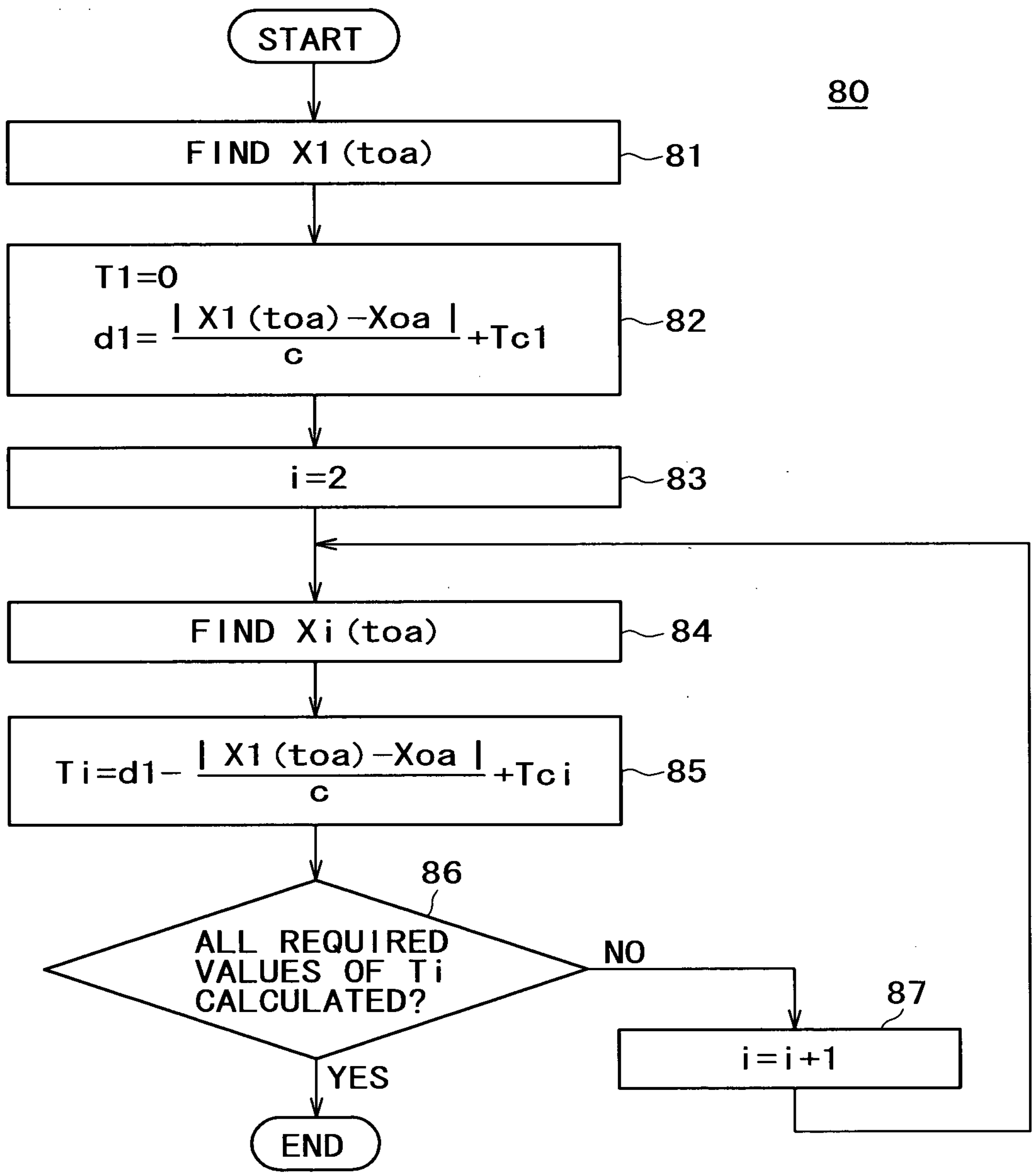

80
START
FIND X1 (toa)
81
T1=0
d1= | X1 (toa) −Xoa | / c +Tc1
82
i=2
83
FIND Xi (toa)
84
Ti=d1− | X1 (toa) −Xoa | / c +Tci
85
86
ALL REQUIRED VALUES OF Ti CALCULATED?
NO
87
i=i+1
YES
END

FIG. 19

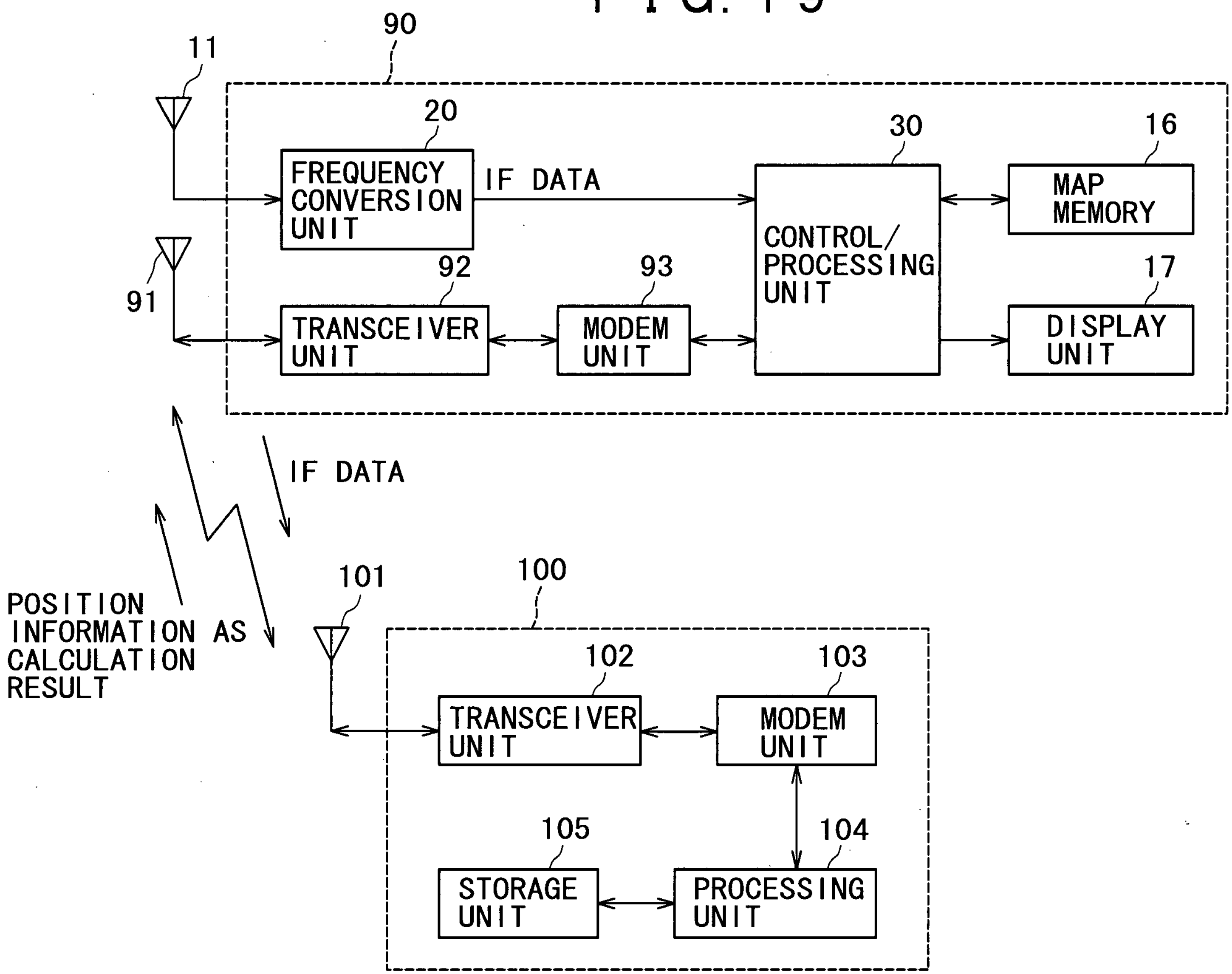

90
11
20
FREQUENCY CONVERSION UNIT
IF DATA
30
CONTROL/ PROCESSING UNIT
16
MAP MEMORY
17
DISPLAY UNIT
91
92
TRANSCEIVER UNIT
93
MODEM UNIT
IF DATA
POSITION INFORMATION AS CALCULATION RESULT
101
100
102
TRANSCEIVER UNIT
103
MODEM UNIT
105
STORAGE UNIT
104
PROCESSING UNIT

FIG. 20

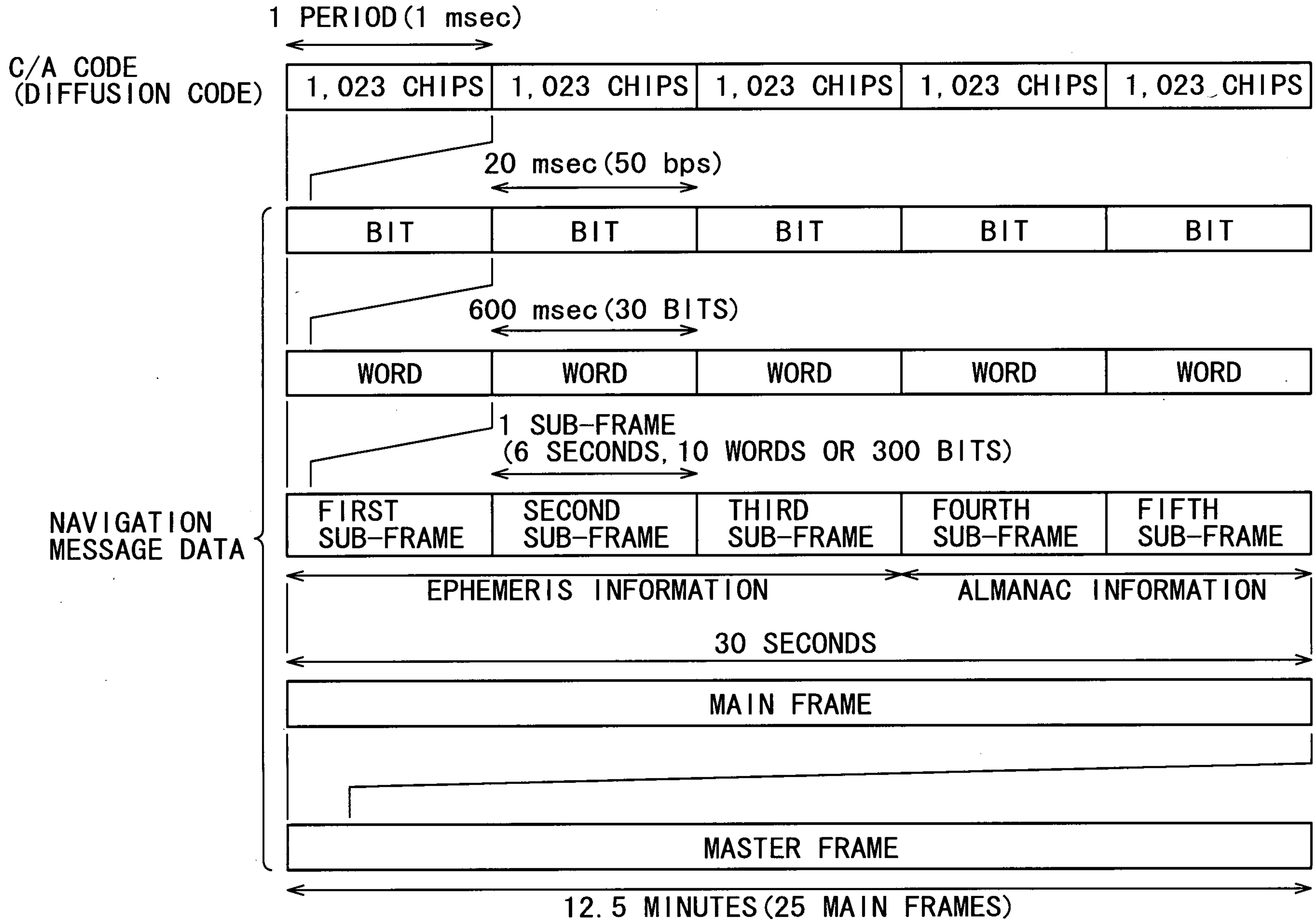

1 PERIOD (1 msec)
C/A CODE (DIFFUSION CODE)
1,023 CHIPS
1,023 CHIPS
1,023 CHIPS
1,023 CHIPS
1,023 CHIPS
20 msec (50 bps)
BIT
BIT
BIT
BIT
BIT
600 msec (30 BITS)
WORD
WORD
WORD
WORD
WORD
1 SUB-FRAME (6 SECONDS, 10 WORDS OR 300 BITS)
NAVIGATION MESSAGE DATA
FIRST SUB-FRAME
SECOND SUB-FRAME
THIRD SUB-FRAME
FOURTH SUB-FRAME
FIFTH SUB-FRAME
EPHEMERIS INFORMATION
ALMANAC INFORMATION
30 SECONDS
MAIN FRAME
MASTER FRAME
12.5 MINUTES (25 MAIN FRAMES)

FIG. 21

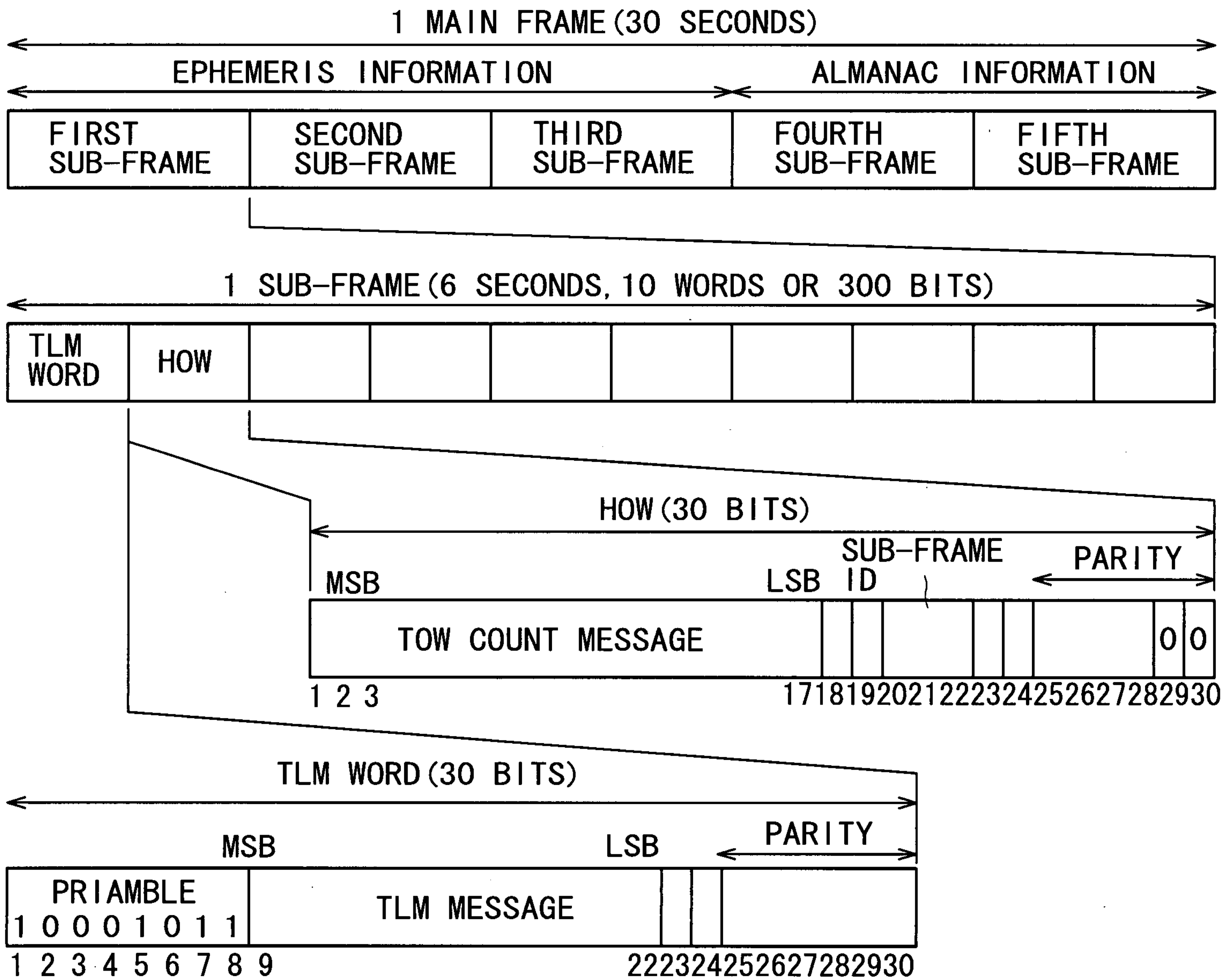

1 MAIN FRAME (30 SECONDS)
EPHEMERIS INFORMATION
ALMANAC INFORMATION
FIRST SUB-FRAME
SECOND SUB-FRAME
THIRD SUB-FRAME
FOURTH SUB-FRAME
FIFTH SUB-FRAME
1 SUB-FRAME (6 SECONDS, 10 WORDS OR 300 BITS)
TLM WORD
HOW
HOW (30 BITS)
MSB
LSB
SUB-FRAME ID
PARITY
TOW COUNT MESSAGE
0 0
1 2 3
17181920212223242526272829 30
TLM WORD (30 BITS)
MSB
LSB
PARITY
PRIAMBLE
1 0 0 0 1 0 1 1
TLM MESSAGE
1 2 3 4 5 6 7 8 9
222324252627282930

FIG. 22A

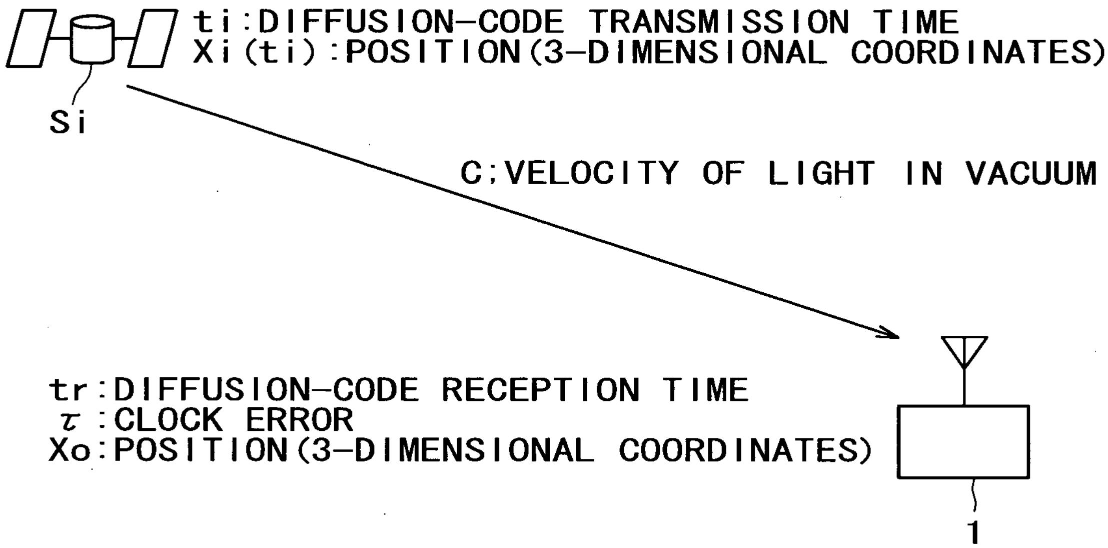


FIG. 22B

$$|Xi(ti)-Xo|-c\{(tr-ti)+\tau\}=0 \quad \cdots\cdots (91)$$

$$Xi(ti)=(xi(ti)\ \ yi(ti)\ \ zi(ti))^T \quad \cdots\cdots (92)$$

$$Xo=(xo\ \ yo\ \ zo)^T \quad \cdots\cdots (93)$$

$$|X1(t1)-Xo|-c\{(tr-t1)+\tau\}=0 \quad \cdots\cdots (91a)$$

$$|X2(t2)-Xo|-c\{(tr-t2)+\tau\}=0 \quad \cdots\cdots (91b)$$

$$|X3(t3)-Xo|-c\{(tr-t3)+\tau\}=0 \quad \cdots\cdots (91c)$$

$$|X4(t4)-Xo|-c\{(tr-t4)+\tau\}=0 \quad \cdots\cdots (91d)$$

$$f4(Xo)=|Xo|-|Xoa|=0 \quad \cdots\cdots (95)$$

Xoa: APPROXIMATE POSITION OF RECEIVER